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ABSTRACT

This report presents a national agenda for research on the learning of thinking skills via computer technology which was developed at a National Academy of Sciences conference on educational, methodological, and practical issues involved in the use of computers to promote complex thought in grades K-12. The discussion of research topics agreed upon by conference participants is summarized under four subgoals: (1) research on higher order thinking; (2) research and evaluation of school efforts to teach higher order thinking; (3) research, development, and evaluation of ways in which computers can be used to teach higher order thinking, including the interactive and motivational capabilities of computers; and (4) research on ways in which schools can use computers. Current research in each area is reviewed, and the need for further investigation is articulated. Eight papers presented at the conference are listed in the preface, and a 50-item references is provided. (MES)

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Program Report 86-15

MEETING THE CHALLENGE: COMPUTERS AND HIGHER ORDER THINKING

A Research Agenda

Janice H. Patterson and Marshall S. Smith

Report of a research conference held at the
National Academy of Sciences, Washington, DC,
October 31-November 1, 1985

Wisconsin Center for Education Research
School of Education
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Chairmen's Preface

In late October 1985, a group of scholars gathered at the National Academy of Sciences in Washington, DC, to discuss the educational, methodological, and practical issues surrounding the use of computers to promote complex thought in grades K-12. Conference participants included researchers whose expertise covered a broad spectrum of substantive areas, but all shared a belief that computers, used in a sound, creative, and integrative manner, can facilitate and improve student thinking skills.

To develop a research agenda that focuses on the learning of thinking skills via computer technology, eight papers were presented by representatives of universities, government, and private industry; discussants for the papers represented a broad range of substantive expertise and backgrounds:

1. "Information Technology and Mathematics: Opening New Representational Windows"

   Jim Kaput, Educational Technology Center, Harvard University; Southeast Massachusetts University

   Discussant: Senta Raizen, National Research Council Commission on Behavioral and Social Sciences and Education

2. "The Teacher Must Be An Active Participant: Supporting Software and Software Supporting"

   Steve Davis, North Carolina School of Science and Mathematics

   Discussant: Gerald Kulm, OERI, U.S. Department of Education

3. "The Having of Important Ideas"

   Tom O'Brien, Southern Illinois University

   Discussant: Alan Ginsburg, Division of Planning and Technical Analysis, U.S. Department of Education

4. "The Role of Software in Higher Order Thinking"

   Janice H. Patterson and Marshall S. Smith, Wisconsin Center for Education Research, University of Wisconsin-Madison

   Discussant: Ann Lewin, Capital Children's Museum, Washington, DC

5. "Cognitive Consequences of Microcomputer Applications"

   Ellen Mandinach, Educational Testing Service

   Discussant: Ed Esty, OERI, U.S. Department of Education

6. "Transfer of Thinking Skills"

   Roy Pea, Bank Street College of Education

   Discussant: Andrew Molnar, National Science Foundation

7. "Computer Supported Intentional Learning Environments"

   Marlene Scardamalia, Center for Applied Cognitive Science (OISE)

   Discussant: Ramsay Selden, Council of Chief State School Officers

8. "Computers, Videodiscs and the Teaching of Thinking"

   John Bransford, Robert Sherwood, and Ted Hasselbring, Learning Technology Center, Vanderbilt University

   Discussant: Susan Chipman, Office of Naval Research

In addition to their conference papers, the authors and discussants were asked to summarize their research priorities, in terms of both issues and projects. This set of eight papers and a variety of software demonstrations laid the groundwork for our discussion, which culminated in the research agenda proposed here.

This conference and report resulted from the combined efforts of many people. In particular, we would like to thank Oliver Moles, Gerald Kulm, Patricia Butler, and Sylvia Shafto of OERI for their substantive and critical reviews. The National Academy of Sciences provided a setting conducive to productive and challenging interchange. Finally, we are particularly indebted to Senta Raizen and Nancy Geasey for their support.

Introduction: Orientation for a National Research Agenda

The Wisconsin Center for Education Research and the U.S. Department of Education's Office of Educational Research and Improvement convened a conference on computers and complex thinking as a means of focusing attention on the question, What must be accomplished in terms of research, development, and evaluation to realize the full potential of technology as a tool for stimulating students' thinking skills? We expected that creative, open, and thoughtful discussion would result in a research agenda designed to explore and illuminate the answer to this fundamental question. Despite the exemplary efforts of the Learning Research and Development Center conference on the future of computers in education and the research needed to realize the computer's potential (Lesgold & Reif, 1983) and the work of the Committee on Research in Mathematics, Science and Technology Education at the National Academy of Sciences on higher order thinking (National Research Council, 1985), a research agenda linking the two remained unwritten. There are fundamental research questions and applied research questions that must be addressed if we are to progress in our understanding of how computers can be used to facilitate teaching thinking skills in schools. It was the purpose of this conference to produce such an agenda.

We recognize that the definition of higher order thinking is a conceptual swamp. As long ago as 1910, John Dewey labeled a similar concept "reflective thinking" and portrayed it as disciplined, purposeful, well supported, and consequential. Dewey argued that "the function of reflective thought is, therefore, to transform a situation in which there is experienced obscurity, doubt, conflict, disturbance of some sort, into a situation that is clear, coherent, settled, harmonious" (Ratner, 1939, p. 851).

In recent years cognitive scientists have advanced our understanding of ways to recognize higher order thinking when it occurs. According to their perspective, higher order thinking is nonalgorithmic and complex; often yields multiple solutions; involves nuanced judgment and interpretation; involves the application of multiple criteria, which sometimes conflict with one another; often involves uncertainty; means self-regulation of the thinking process; involves imposing meaning, finding structure in apparent disorder (Resnick, in press).

Whatever we call it--reflective thought, higher order thinking skills, reasoning, critical thought, or problem solving--we are under no illusion that the conference or this research agenda can provide a definitional consensus; there are nearly as many labels for and definitions of the concept as there are researchers investigating its value and characteristics. Many scholars agree, however, that higher order thinking includes the ability to synthesize and analyze diverse sources of information, to generate multiple solutions, and to discern structure amidst disorder. To facilitate our progress toward a research agenda, conference participants agreed--albeit hesitantly--to accept a working definition: "Higher order thinking is the engagement of a person in active and sustained cognitive effort directed at solving a complex problem" (Patterson & Smith,

1986, p. 2). There was, certainly, simultaneous and explicit recognition of the idea that higher order thinking is individual and not easily assessed.

We saw our task as creating a research agenda that includes applied and basic research as well as development tasks. In some cases, we discussed knowledge we don't have and, as yet, are uncertain how to pursue. In other cases, we identified knowledge we can get through a systematic research agenda. For instance, conferees recognized that to persuade skeptics about the power of wedding computers and higher order thinking, we need systematic, rigorous evaluation of the effects of computers as learning tools. We worked on these tasks by considering barriers to using computers to facilitate thinking in schools.

Vision of Schooling

Our goal can be stated simply: By the year 2000, the typical United States elementary or secondary school will routinely use computers to assist teachers in engaging students in higher order thinking.

Envision, for example, a fifth-grade classroom in which the teacher routinely uses computers in all subject areas to facilitate student thought. Every student has unlimited access to a microcomputer that is electronically linked to the teacher's machine. In reading and language arts, students use a word processor that diagnoses gaps in their arguments as they prepare compositions defending their positions on nuclear disarmament. Within that program, an encyclopedic function allows them to check basic statistics on the presumed effects of a nuclear winter. A thesaurus and spelling and grammar checker are part of the software package. After students have completed and edited their manuscripts, they pass them electronically to other students in their school who are working on the same topic with the expressed purpose of seeking feedback on their arguments and writing style.

Later that morning, they use a computer-assisted design program to create a model home that allows maximum sunlight with the least possible heat loss. The program encourages students to rotate the structure and consider the insulating effects of different building materials. In science class, they connect electronically with computers in the state's department of natural resources to access current information on the effects of recent flooding in their state. Careful monitoring of those data raises concern about the reduced food supply for water fowl. They create computer charts to display their findings for a letter to the editor of the local newspaper. In music class, students work in small groups to create original compositions that will later be presented to the class. The teacher plans to build on this experience later, requiring that students use these compositions for a concert by an entire orchestra, all simulated on the computer.

Our vision goes beyond scientific activities to look at the teacher's role and the structure of a school that supports these practices. Teachers are not at the front of the room lecturing to the class; they are working

with small groups or individuals and focusing on content and the process of learning. They are not computer programmers and don't focus on the intricacies of the hardware. Rather, they see computer use as a powerful strategy for increasing student access to vast amounts of data that provide information for observing trends and solving problems. Teachers use the technology to assist in such areas as diagnosing students' learning difficulties, identifying prescriptive activities, and maintaining up-to-date student records. No longer do these teachers receive students' achievement scores on the last day of school; the scores are electronically available whenever needed. Computer conferencing capabilities facilitate discussion with the school psychologist and local pediatrician on a particular child's absence.

A Research Agenda

Success in achieving our vision, or major goal, depends on the accomplishment of a series of lesser subgoals. These four research topics, agreed on by conference participants, drive our research agenda:

1. Research on higher order thinking.

2. Research and evaluation on how schools teach higher order thinking.

3. Research, development, and evaluation on how computers can help schools teach thinking.

4. Research and evaluation on how schools can use computers effectively.

1. Research on higher order thinking. Conference participants concurred that increased understanding of issues related to higher order thinking are fundamental to the pursuit of our vision. Conferees Marlene Scardamalia and Roy Pea presented conference papers that delineated important issues. Scardamalia, for example, talked about the importance of research and development activity that enhances our knowledge about students' ability to monitor, control, and improve their own learning. Pea argued for increasing research efforts to learn more about the social context in which students learn most effectively. We agreed that a basic research agenda should focus on activities that enhance our understanding about how students think and how to facilitate their thinking.

2. Research and evaluation of school efforts to teach higher order thinking. Many barriers must be overcome for students to improve their thinking skills in schools, including a weak curricula, few alternatives for teacher training, and the structure of the school. As just one example, O'Brien's conference paper reminded us that, although the purpose of learning mathematics is to help students construct important ideas, relationships, and strategies that allow them control over their world, much of current curricula is limited to rote learning. Vigorous research and

evaluation efforts that examine barriers, such as the curriculum described by O'Brien, are needed. Only a systematic evaluation of curricula, teacher training, and organizational barriers within schools will advance our goals.

3. Research, development, and evaluation on how computers can be used to teach higher order thinking. Conferees expressed robust agreement for an agenda that addresses ways computers and related technologies could be used to facilitate student thinking and problem solving skills. Many ideas were expressed. Among them, Mandinach discussed the importance of learning more about the chain of cognitive accomplishments necessary for students to learn computer programming skills and their relationship to improved problem solving. Kaput described three software programs and the ways they move students beyond the concrete and situation-bound to a representational view that links ideas in many different ways and at different levels of abstraction. John Bransford's paper described a prototypic effort to link computers with videodisks to teach problem-solving skills. Patterson and Smith agreed that visionary prototypic efforts like these are needed, and they also provided a theoretical framework that suggests how existing software could be used to promote thinking skills as well as directions for improving that software. There was widespread agreement among conferees about the need for a basic and applied research agenda that addresses these issues.

4. Research on how schools can use computers. Conferees recognize that our goal of computer use in schools to teach thinking skills will go unrealized if there are not thoughtful, systematic investigations about the barriers schools face that obstruct all kinds of computer use. For example, Davis discussed the importance of the teacher's role, and how that role could evolve, as one area needing examination. He argued that software that teaches and supports the teacher has the greatest chance of acceptance in classrooms as opposed to "stand alone" and "teacher-proof" software. Other participants discussed the importance of examining the effect of teacher and computer learning and the implications for restructuring schools similar to our vision of schools in the year 2000 described earlier.

The remainder of this document describes the activities that need to be accomplished to produce the state of schooling detailed in our vision. For each subgoal, we have imagined the knowledge necessary to achieve it and developed a research agenda to produce that knowledge.

Research on Higher Order Thinking

Critical to advancing our goal of using computers to facilitate student thinking is increased knowledge about how people think. Research is needed to resolve one of the great debates among those who wrestle with the definition, instruction, and assessment of higher order thinking: Is there a set of general heuristic strategies that can transfer across domains to produce better problem solvers? Several studies have shown that knowledge and use of heuristic strategies can improve problem-solving ability (Mayer & Bovenmeyer, 1984; Schoenfeld, 1979, 1982). Other evidence suggests that

these strategies are effective only to the extent that they are embedded in a content domain and that, as students move deeper into specific content, they develop problem-solving skills useful primarily in that domain (Glaser, 1984). While students may become more successful problem solvers, that success is believed to be directly related to their conceptual understanding of the material.

Evidence in support of this latter view can be found in the literature on novice and expert problem solving (Chi, Feltovich, & Glaser, 1981). This research concludes that experts and novices approach problems differently, based on their conceptual understandings in the content domain. Novices focus on the literal objects identified in the problem statement. Experts, on the other hand, delve more deeply into their understanding of the concepts and their interrelationships, as well as the procedures specific to the content domain (Larkin, McDermott, Simon, & Simon, 1980). Thus problem-solving success may depend on conceptual understanding of material in a specific content domain and not just on the knowledge or use of a set of heuristic strategies, but more data are needed to reject or confirm this hypothesis.

Student misconceptions may be a significant barrier to the transfer of thinking skills to a project or problem. Resnick (in press) suggested that students' misinformation serves as a barrier to acquiring new knowledge or to transferring what they have learned in the classroom to real-life settings. Other research (Champagne, Klopfer, & Anderson, 1980) has demonstrated that college students' inaccurate ideas about common physical situations interfere with their learning of basic principles of physics.

Investigations are needed of how people can organize and represent knowledge so that it is easily retrieved and useful for solving problems and assimilating new information. The ways in which knowledge is structured can greatly affect the ease or difficulty of using that knowledge for intellectual tasks. Studies that enhance these general understandings may point the way for future investigations in specific content areas. If the importance of conceptual knowledge is increasingly recognized as a prerequisite for solving problems, it will be important to pursue further studies on the structure of content and strategies particular to an area. In other words, how does the varying structure of different subject areas influence ways in which new knowledge is acquired or the way in which that knowledge is used to solve complex problems?

Research in metacognition could reconcile the tension between general heuristic skills and the structure and role of knowledge (and potential misconceptions in successful problem solving). Metacognitive theorists find that those who self-consciously reflect on their own thought processes can enhance their thinking skills, and recent research indicates that students actively select, interpret, and even alter the content of instruction (Brown, 1978; Ryan, 1984). Monitoring of one's thought processes involves planning activities prior to undertaking a problem, such as predicting outcomes and scheduling strategies; monitoring activities during learning; and checking outcomes. The disciplined use of these strategies is thought

to provide executive control for the learning process (Brown, Bransford, Ferrara, & Campione, 1983). Studies in this area are small in number and need to be replicated with diverse student populations.

There is much we don't know about human thought processes, problem solving, and the transfer of learning skills across content domains. Research into these fundamental issues is essential if we are to come to an understanding of the ways we can best facilitate the instruction and practice of complex thinking skills in our schools. Conferees agreed that our knowledge could be significantly advanced by a research agenda that asks these questions:

1. Is there a set of general heuristic strategies that transfer across content domains to produce better problem solvers?

2. How much depth in content is needed to provide a conceptual base for problem solving?

3. What strategies are effective in helping students overcome misconceptions that interfere with their thinking?

4. How should knowledge be organized and represented so that it is easily retrieved, useful for solving problems, and readily assimilates new information?

5. How does the self-conscious reflection of individuals' thought processes affect their thinking?

Research on Teaching Thinking in Schools

Conferees acknowledged that the evaluation of existing curricula and the development and evaluation of new curricula are essential. There have been several attempts to teach higher order thinking in recent years (DeBono, 1983; Feuerstein, 1980; Lipman, Sharp, & Oscanyan, 1980), but systematic, longitudinal evaluations of these programs have not been carried out. Conference participants agreed that a major experiment is needed.

Realizing that students need explicit training to develop complex mental processes and to monitor their own thinking, some educators have developed new school curricula designed to foster thinking skills. Some programs teach heuristic strategies in a nearly content-free environment; some use generally familiar knowledge; others focus on specific problem-solving skills in the context of the acquisition of basic skills (Glaser, 1984). None target teaching heuristics in substantive content areas, except for mathematics, in spite of advances in cognitive science that advocate this direction. We need research that builds on the work of cognitive scientists (Greeno, 1978; Larkin, 1985; Mayer, 1975; Siegler, 1985) to better understand how these programs affect thinking skills across the curriculum. In addition to understanding how heuristics combine to facilitate students' thought processes, we need new knowledge about the

effects of specific strategies, particularly when they are the foundation for "thinking skills curricula."

For instance, pairing students to analyze and solve problems is noted as an effective strategy for promoting student thinking. Reports assert that students help each other in productive ways, cooperate in completing tasks, and progress in defining problems neither partner understood at the outset (Mehan, Moll, & Reil, 1985). But unfortunately, only a few studies have been conducted to assess the effectiveness of the paired learning approach. Anecdotal accounts indicate that participants believe the program does facilitate problem-solving skills in probability, computer programming, and chemistry (Whimbey, 1984), but formal evaluation is needed to establish its value.

There is an immediate need to measure higher order thinking so that we can know more about the programs that promise to teach it. The nature of tests affects the teaching of higher order thinking in the schools. Tests drive the curriculum, but they do not include valid and reliable measures of higher order thinking. Standardized achievement tests fail to evaluate whether or not students are learning complex thinking skills. In fact, many argue that the very nature of these tests--and the accompanying classroom emphasis on discrete bits of disaggregated information--discourage schools from attempting to promote or teach reflective thought (Fredericksen, 1984). Test domains are rigidly defined and rarely require students to compare or synthesize data across domains. Even the most recent attempts by Robert Sternberg and the Connecticut State Department of Education to assess thinking relied on a multiple-choice format. In addition to not assessing thinking skills, standardized tests exert a nagging, unyielding pressure on schools and curricula to teach to the test. In a time of dwindling resources, limited time, and greater demands on teachers, few educators would question the reasons for focusing on material that they expect to appear on the standardized tests. Thus it becomes critical to develop tests that measure higher order thinking; those tests, used in schools, promise greater emphasis on student thinking.

We also need to be able to assess the quality of individual thinking, including the capability to assimilate new information, analyze a problem from different perspectives, and test different solutions to complex problems in a variety of subject areas. Studies are needed that begin to assess knowledge about what constitutes complexity for one person and not another. Different types of assessment will be needed for individuals and programs designed to teach thinking skills. Assessment efforts are needed that assess the depth of student knowledge and how that knowledge is used to solve complex problems. Innovative approaches to assessment and evaluation could lead us to simulations and thinking protocols that can be compared with those of experts in particular subject areas.

The effects of curriculum and testing notwithstanding, whether or not higher order skills are taught in classrooms depends to a great extent on teachers' motivation, knowledge and training. Recent criticisms of schooling practices (Boyer, 1983; Goodlad, 1983; Sizer, 1984) and analyses

of test results have suggested that most schooling consists largely of the rote learning of facts, simple algorithms, and routine procedures; higher order skills such as analysis, critical thinking, and problem solving commonly are given short shrift, if they are considered at all. Studies of reading instruction, for example, find that 90 percent of instruction is directed at the learning of isolated words and only 5 percent is focused on understanding text (Selden, 1984). O'Brien noted that, for example in mathematics education, elementary school students spend endless hours carrying out simple computational procedures, and that more advanced classes bring nothing more than more advanced procedures--this time in algebra, trigonometry, and calculus.

Rationales for this situation abound, but one thing is certain: current teacher-training practices do not prepare teachers to instruct students in higher order skills. A lack of preservice training is bolstered by job conditions that include scheduling constraints, such as the 50-minute class period, that are not conducive to the flexible environment that facilitates analysis and problem solving. Teachers faced with a classroom of 30 students, many with special needs, may be reluctant to relinquish the control and structure implicit in seatwork and paper-and-pencil drill and to replace it with the comparatively chaotic, group-oriented processes of problem solving. In the face of such pervasive, institutionalized opposition to change, we need to know more about the individual and institutional barriers that enhance or inhibit the teaching of thinking skills.

We envision studies that address the following questions:

1. How much subject-matter knowledge do teachers need to be able to use substantive concepts to pose complex problems?

2. Should teachers be systematically trained in using heuristic strategies across different content areas in their preservice work with the hope that if they become better problem solvers they will be better able to teach those skills?

3. Should tests be developed to assess prospective teachers' skill in solving problems and in teaching problem solving skills?

4. What does a successful model for teaching higher order skills include at the secondary level? at the elementary level?

5. What instructional methods are most effective in teaching thinking skills? Do they vary in effectiveness for students of different abilities?

Research on Computers and Higher Order Thinking

Conferees agreed that progress toward our major goal of using computers to teach thinking skills requires active research and development efforts

that focus on the unique features of computers. We also agreed that two fundamental characteristics of computer technology make it distinct from other technologies and educational tools: microcomputers are creatively interactive and can bring an unparallelled "brute-like" intellectual force to single-minded tasks; and they are intrinsically motivating, both cognitively and socially. In the following pages we look briefly at what research suggests and identify unmet needs for further work in each area.

Interactive Capability of Computers

The computer's ability to interact with students is important in two ways. First, it allows interaction with content, such as access to demographics from the U.S. Census Bureau for students writing an argument for increased funds for after-school daycare. Second, computers can provide tools for the interaction of different procedures, such as the facility to move back and forth between a word processing program and a data-base management system that would facilitate writing the argument and displaying the data to suggest that the rise in single-parent homes and in two-career families necessitates the development of after-school daycare.

The computer's capacity for students' interaction with content is critical to advancing our goal. In an earlier section of this report, we discussed the differences between experts and novices in problem solving in a content domain. Experts solve problems based on their understandings of conceptual relationships within that domain; novices, however, rely on surface information to solve problems. Several studies have pointed to the importance of rich content as a basis for thinking (Champagne, Klopfer, & Anderson, 1980; Glaser, 1984; Larkin, McDermott, Simon, & Simon, 1980), but conferees worried that we know little about how students use computers to access information that facilitates their thinking or how they identify and select the needed knowledge. Specifically, we need to know under what conditions students seek information to aid them in solving problems or building arguments as well as what knowledge they seek. As a first step, we need to know more about how computers might help students to assess their level of existing knowledge. We also need to know more about how knowledge should be structured on the computer to facilitate students' assimilation of it.

To advance our understandings about ways students interact with subject matter on the computer, we need to develop an educational courseware system that spans all content areas and includes multiple variations for content presentation within each domain. Just as curricula for ninth-grade social studies vary across states, so should materials designed to teach these topics. A more integrated curriculum could result that culls knowledge from one content to another.

Conferees concurred that it is also important that student interaction with content includes using the computer to solve problems across subject areas. Repeated success in solving problems in a variety of content areas reinforces student use of strategies in new but similar situations.

Psychologists endorse training in multiple contexts because it decreases the likelihood that a particular piece of information will be welded to a particular context (Brown, Bransford, Ferrara, & Campione, 1983; Brown, 1974). Herb Simon (1973) noted the importance of practice in solving ill-defined and well-defined problems; we need data that document the effects of solving both types of problems within content areas and within a computer environment. Systematic evaluation efforts that assess the effects of student use of problem-solving courseware is critical to advancing knowledge about how students can interact with content to enhance their thinking.

The second category of computer interaction focuses on tool software. Software used as a tool may help students analyze their own problem-solving strategies; capture student interest, thereby increasing motivation; present multidisciplinary problems that demand that students bring to bear information and knowledge from a wide variety of content domains; and teach students "executive thinking skills" such as goal setting, strategic planning, checking for accurate plan execution, goal-progress monitoring, plan evaluation, and plan revision.

Tool software is designed to remove task drudgery to free the mind for creative thought. Brown (1984) referred to these systems as "empowering environments." Examples include applications programs such as word processors, idea processors, data-based management systems, and the more innovative musical systems. Scardamalia and Bereiter, for example, have developed the concept of computer supported intentional learning environments, software programs designed to enhance student thinking skills. Such programs teach students the problem-solving processes identified as part of an expert's approach to solving novel problems: questioning beliefs, identifying gaps in knowledge, expressing confusions, identifying difficulties, considering an idea from multiple perspectives, searching memory, and evaluating ongoing processes. By presenting information, eliciting responses, and evaluating performance, such programs provide feedback to individual students in ways that should enable them to consider and improve their own thought processes. We need data to know how effective these programs are.

Motivational Capability of Computers

Observers have noted that students who appear to have little, if any, academic engagement in school subjects may spend hours engrossed in a video game; inherent in computer technology is the capability to infuse into students a motivational drive unparallelled by other teaching tools. Some educational software attempts to tap into that motivation and to bring it to bear on the learning of complex thinking skills.

Examples of software that use entertainment to motivate learning are the Thinker, the Producer and the Empiricist, developed by Bransford, Sherwood, and Hasselbring at the Learning Technology Center at Vanderbilt University. These programs create contexts for problem solving by using

intact segments from such popular films as Raiders of the Lost Ark and Star Wars. Students attempt to extract from the movie segments information relevant to solving the problems portrayed in the scenes; the programs allow students to replay the scenes to reexamine the events and to generate their own problems and lessons.

On one hand, game-like, or entertaining, software is considered likely to engage student attention, require more active processing, and result in improved learning. On the other hand, such entertainment frills are considered distractors that impair learning; teachers express worry about the flashiness and glitter distracting students from substantive material. There appears to be evidence to support both positions. Salomon (1983) proposed that motivational enhancements may influence the initial level of students' involvement, but that successful learning (as opposed to entertainment) may be directly related to the level of the cognitive activity required. That is, motivational techniques that produce increased arousal are likely to enhance performance at early stages of learning but interfere at later stages in the process (Spence, 1956). Intuition tells us that entertaining, game-like software captures and holds students' attention, thus motivating them to solve problems and engage in higher-order thinking. Some research suggests that such software may distract students, rather than enhance their learning. Systematic evaluation of the effects of game-like software on student thinking and motivation is sorely needed. Intrinsic motivation very likely exerts tremendous influence on students' engagement in school work (Lepper & Chabay, 1985), but few advances have been made in understanding the components of motivation for different students under varying conditions of instruction. Even less progress has been made if one expands the issue to include the use of one computer by two students.

When pairs of students work on the computer, the additional motivation of student social interaction may contribute to their thinking skills. Earlier we noted that paired problem solving can contribute to increased success in solving problems. Limited evidence suggests that significantly more collaboration occurs between children when using a microcomputer than when working on other classroom tasks (Hawkins, Sheingold, Gearhart, & Berger, 1982). Some software even requires that two students work collaboratively at one computer (Dickson, 1985; Dickson & Vereen, 1983). One study suggested that cooperative peer interaction emerged and teachers were able to achieve educational goals that could not have been achieved as readily had a microcomputer not been used (Mehan et al., 1985). But more data are needed on the effects of dyadic work with a microcomputer, particularly the effects on higher order thinking.

In this section targeting research on computer use to facilitate higher order thinking, we have addressed two primary areas related to the unique capabilities of the computer: interaction and motivation. We briefly described existing research and suggest that the following questions be addressed:

1. How can the computer help students work and solve problems in content domains?

2. How do students select knowledge available in a computer environment that will support thinking and problem-solving activity?

3. How can computers present knowledge in different ways in different content areas to promote higher order thinking?

4. How can computers be used to present both ill-defined and well-defined problems across content areas?

5. How can the computer's motivational capacity be maintained beyond the initial stage of engaging students?

6. What software characteristics reduce student motivation?

7. What are the cognitive effects of software created for use by pairs of students?

Research on Computer Use in Schools

> . . . the computer presence will enable us to so modify the learning environment outside the classroom that much if not all the knowledge schools presently try to teach with such pain and expense and such limited success will be learned as the child learns to talk, painlessly, successfully and without organized instruction. (Papert, 1980, p. 16)

Statements of this genre can prompt criticism and doubt. Skeptics urge that we learn from past mistakes with radio, television, and programmed learning technologies and that we sink no more resources into research on educational technology. Justifiably, they point to documented problems with computer use in schools (Patterson & Patterson, 1983; Wilkinson & Patterson, 1983); hardware acquisition and obsolescence (Becker, 1986; Cline, Bennett, Kershaw, Schneiderman, Sticher, & Wilson, 1986); software (J. S. Brown, 1983); teacher training (Shavelson, Winkler, Stasz, Feibel, Robyn, & Shaha, 1984); curriculum integration (Walker, 1986); and equitable distribution of resources (Becker, 1986).

If computers are to be used effectively in the classroom, these problems must be resolved; many scholars and educators continue to concentrate their efforts toward that end. Because these problems are addressed in other forums, and because several will disappear as the technology matures, conference participants chose to address research and development issues specifically related to the use of computers in schools.

A major problem facing advocates of computer use in schools and the advancement of our vision of what the school should be in the year 2000 is the lack of consensus on what, or whether, children learn from using computers. Many claims have been made about the benefits of computer-assisted instruction (Papert, 1980; Taylor, 1980). Most studies examining computer technology have focused on programmed instruction, drill and practice, and other computer-assisted instruction programs because these are among the oldest formats for computer instruction. Unfortunately, some of these studies offer conflicting results; others were poorly designed. Rigorous, longitudinal evaluations of computer use in schools must be initiated to measure the effects of computer-assisted instruction on student achievement. Studies need to be initiated that compare computer instruction with other categories of instruction. These assessments should focus on issues noted for their effect on student learning, including time on task and student engagement.

No use of the computer in schools will proceed without the widespread support of teachers. Without diminishing the importance of the teacher in the classroom, research must be initiated that looks at the effect of computers and related technologies on the role of teachers. Educational change becomes part of the institution only when teachers feel they are part of the change. Cuban argued that "the new technology, like its predecessors, will be tailored to fit the teacher's perspective and the tight contours of school and classroom settings" (1986, p. 99). Conferees agreed that the teacher decides what goes on in classrooms; the teacher adapts and often transforms directions from other sources and is the final arbiter of what will and will not transpire in the classroom. Thus, better understanding of how the computer can be used to support teacher-selected activities may be crucial to furthering school use of computers. Efforts should be directed toward prototype systems that teachers want and that can save time and free them for other activities. Unfortunately, there are very little data to suggest what form this software or other teacher support might take or, indeed, how the teacher views computer use in schools.

We also acknowledge that teachers face organizational barriers presented by school and classroom settings that are outside their control and that must be addressed if we are to advance widespread use of computers in schools. Current speculation about the need to restructure schools, particularly secondary schools, opens possibilities for futuristic uses of computers that would radically alter teacher roles, the structure of the school day and alternatives for student learning. A simple example illustrates the point that organizational changes may facilitate computer use in schools. In some instances, computers are housed in individual classrooms; in other instances, they are placed in computer laboratories. Research indicates that in schools that group computers in computer labs, more students use them and are more likely to use them before and after school hours (Becker, 1986). Clearly, if we are to advance our subgoal of increased computer use in schools, a set of studies must be instigated that addresses questions such as the following:

1. Under what conditions are computers effective in teaching students instructional material?

2. What conditions can the computer provide that will increase students' time on task?

3. How does computer-assisted instruction compare with other forms of instruction?

4. Does computer use in the classroom change the role of the teacher? If so, how is that role altered?

5. How can computers be used to further teachers' goals for classroom activity and to support teachers in other job-related activities?

6. How do teachers view the use of computers in schools? What do teachers believe would be an effective strategy for computer use in schools?

7. What organizational factors of schools and classrooms promote or inhibit the uses of computers?

In light of the noted barriers, some observers (Nathan, 1985) maintain that introducing computers into the classroom is an unnecessary and premature complication, that computers should be considered only after other, more pressing educational issues have been resolved. Alternatively, computers could become the catalyst needed to trigger change, to break schools out of their routine approaches to curriculum, and to prompt teachers and administrators to focus on the need to teach higher order thinking skills.

The computer has revolutionized all aspects of modern society; it is, according to Lesgold and Reif (1983), "a one-in-several-centuries innovation" (p. 1). It could work the same magic in the classroom that it has in business, in government, and in medicine. The computer has become integral to the Armed Forces, to the profession of architecture, and to pilot training; it is a key tool in medical diagnosis and an irreplacable resource to lawyers, accountants, scholars, librarians--to all professionals who can benefit from the rapid, accurate, and precise presentation of information. Its potential for instructional use was described eloquently in a 1983 conference report (Lesgold & Reif); we wanted to expand on the ideas in that report and to bring them to bear on the issue of computer use in schools.

Conclusion

With the vision of what is possible by the year 2000, we have crafted a research agenda that will move us toward our goal of using computers K-12

across all content areas to improve student thinking. To accomplish this goal, we identified four subgoals to guide our agenda:

1. Research on higher order thinking

2. Research and evaluation on how schools teach higher order thinking

3. Research, development and evaluation on how computers can help schools teaching thinking

4. Research and evaluation on how schools can use computers effectively

We have discussed current research in each of these substantive areas--and articulated the conviction of conferees that further investigation is needed. It is our hope that the issues outlined here will become the basis of a national research agenda, designed to elucidate and to enhance the role technology will play in teaching students to think, to question, and to solve problems. We also hope that this report will be recognized as the synthesis of many ideas, that it will trigger further discussion, and ultimately, that it will help to instigate the kinds of investigation and research that it recommends.

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